
Professor Jennifer Balakrishnan, jbala@bu.edu

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1 Introduction

- Please refer to the syllabus for all course details.
- Notes will be available online (<http://math.bu.edu/people/jbala/242.html>) for use in each class.

2 Systems of linear equations

Lay–Lay–McDonald §1.1 pp. 2 – 12

Systems of linear equations are central to the study of linear algebra. A number of real-world scenarios can be modeled by a collection of linear equations in a large number of variables. Throughout this course, we will study some of these applications, drawing from physics, applied mathematics, economics, and engineering. Here are two examples:

- *Linear programming and optimization*: Many important management decisions in companies are made on the basis of linear programming models that use hundreds of variables. The airline industry, for instance, uses linear programs that schedule flight crews, monitor the location of aircraft, or plan scheduling of support services such as maintenance and terminal operations.
- *Electrical networks and hardware*: Engineers use simulation software to design electrical circuits and microchips involving millions of transistors. Such software relies on systems of linear equations and other tools from linear algebra.

We begin by introducing some terminology.

A *linear equation* in the variables x_1, \dots, x_n is an equation that can be written as

$$a_1x_1 + a_2x_2 + \cdots + a_nx_n = b,$$

where b and the coefficients a_1, \dots, a_n are real or complex numbers. The subscript n may be any positive integer. (In this course, n will typically be between 2 and 5, but in real-life, n may be very large!)

A *system of linear equations* (or a *linear system*) is a collection of one or more linear equations in the same variables x_1, \dots, x_n . Here's an example:

$$\begin{aligned}x_1 - 2x_2 &= -1 \\ -x_1 + 3x_2 &= 3.\end{aligned}$$

A *solution* of the system is a list (s_1, \dots, s_n) of numbers that makes equation a true statement when the values s_1, \dots, s_n are substituted for x_1, \dots, x_n , respectively. In the example above, $(3, 2)$ is a solution of the linear system (in fact, it is the only solution).

The set of all possible solutions is called the *solution set* of the linear system. Two linear systems are said to be *equivalent* if they have the same solution set.

We'll say more about this in the next section, but one way to understand a system of linear equations is in terms of its solutions: it either has

1. no solution, or
2. exactly one solution, or
3. infinitely many solutions.

We say that a system of linear equations is *consistent* if it has either one solution or infinitely many solutions and *inconsistent* otherwise.

We introduce matrix notation to help denote linear systems. Let's look at the following linear system:

$$\begin{aligned}x_1 - 2x_2 + x_3 &= 0 \\ 2x_2 - 8x_3 &= 8 \\ 5x_1 - 5x_3 &= 10.\end{aligned}\tag{1}$$

The matrix

$$\begin{bmatrix} 1 & -2 & 1 \\ 0 & 2 & -8 \\ 5 & 0 & -5 \end{bmatrix}$$

is the *coefficient matrix* of (1) and

$$\begin{bmatrix} 1 & -2 & 1 & 0 \\ 0 & 2 & -8 & 8 \\ 5 & 0 & -5 & 10 \end{bmatrix}\tag{2}$$

is the *augmented matrix* of the system. The *size* of a matrix refers to how many rows and columns it has. For instance, the matrix (2) is a 3×4 matrix because it has 3 rows and 4 columns. In general, a matrix with m rows and n columns is said to be an $m \times n$ matrix.

Our goal today is to describe an algorithm for solving linear systems. The basic method is to replace one system with an equivalent system that is easier to solve. We have three operations to simplify linear systems:

Elementary row operations

1. Replace one row by the sum of itself and a multiple of another row.
2. Interchange two rows.
3. Multiply all entries in a row by a nonzero constant.

Let's see this in action:

Example 1 *Solve*

$$\begin{aligned}x_1 - 2x_2 + x_3 &= 0 \\2x_2 - 8x_3 &= 8 \\5x_1 - 5x_3 &= 10.\end{aligned}$$

Here are two fundamental questions about a linear system:

1. Is the system consistent; that is, does at least one solution exist?
2. If a solution exists, is it the only one; that is, is the solution unique?

Example 2 *Determine if the following system is consistent:*

$$\begin{aligned}x_2 - 4x_3 &= 8 \\2x_1 - 3x_2 + 2x_3 &= 1 \\4x_1 - 8x_2 + 12x_3 &= 1.\end{aligned}$$